Chapter 5
Conservation

Businesses are finding that by conserving resources, both natural and man-made, and conserving energy, they can cut costs, improve the environment, and improve their competitiveness. Due to the substantial amount of rinse water consumed and wastewater generated by the printed wiring board (PWB) manufacturing process, water conservation is an issue of particular concern to board manufacturers and to the communities in which they are located. This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) evaluates the comparative resource consumption and energy use of the surface finishing technologies. Section 5.1 presents a comparative analysis of the resource consumption rates of the surface finishing technologies, including the relative amounts of rinse water and metals consumed, and a discussion of factors affecting process and wastewater treatment chemicals consumption. Section 5.2 presents a comparative analysis of the energy impacts of the surface finishing technologies, including the relative amount of energy consumed by each process and the environmental impacts of the energy consumption.

5.1   RESOURCE CONSERVATION

Resource conservation is an increasingly important goal for all industry sectors, particularly as global industrialization increases demand for limited resources. A PWB manufacturer can conserve resources through its selection of a surface finishing process and the manner in which it is operated. By reducing the consumption of resources, a manufacturer will not only minimize process costs and increase process efficiency, but also will conserve resources throughout the entire life-cycle chain. Resources typically consumed by the operation of the surface finishing process include water used for rinsing panels, metals that form the basis of many of the surface finishing technologies, process chemicals used on the process line, wastewater treatment chemicals, and energy used to heat process baths and power equipment. A summary of the effects of the surface finishing technology on the consumption of resources is presented in Table 5-1.

To determine the effects that surface finishing technologies have on the rate of resource consumption during the operation of the surface finishing process, specific data were gathered from chemical suppliers of the various technologies, Performance Demonstration participants, and from PWB manufacturers through the Workplace Practices Questionnaire and Observer Data Sheets. Data gathered through these means to determine resource consumption rates include:

- process specifications (e.g., type of process, facility size, process throughput, etc.);
- physical process parameters and equipment description (e.g., automation level, bath size, rinse water system configuration, pollution prevention equipment, etc.);
- operating procedures and employee practices (e.g., process cycle-time, individual bath dwell times, bath maintenance practices, chemical disposal procedures, etc.); and
- resource consumption data (e.g., rinse water flow rates, frequency of bath replacement, criteria for replacement, bath formulations, frequency of chemical addition, etc.).

Table 5-1. Effects of Surface Finishing Technology on Resource Consumption

Resource	Effects of Surface Finishing Technology on Resource Consumption
Water	Water consumption can vary significantly according to the surface finishing process and level of automation. Other factors such as the cost of water, sewage costs, and operating practices also affect water consumption rates.
Metals	Both the type and quantity of metal consumed is dependent on the surface finishing technology used by a facility. Metal plating thicknesses are crucial to surface finishing performance and are set forth in strict guidelines from process suppliers to PWB manufacturers. Facility operating practices can influence metal consumption if baths are not maintained properly causing increased process chemical waste.
Process Chemicals	Reduction in the number of chemical baths comprising the surface finishing process typically leads to reduced chemical consumption. The quantity of process chemicals consumed also is dependent on other factors such as expected bath lives [e.g., the number of surface square feet (ssf) processed before a bath must be replaced or chemicals added], process throughput, and individual facility operating practices.
Treatment Chemicals	Water consumption rates and the associated quantities of wastewater generated, as well as the presence of metal ions and other chemical constituents, can result in differences in the type and quantity of treatment chemicals consumed.
Energy	Energy consumption rates can differ substantially among the baseline and alternative processes. Energy consumption is discussed in Section 5.2.

The focus of this section is to perform a comparative analysis of the resource consumption rates of the baseline [non-conveyorized hot air solder leveling (HASL)] and the alternative surface finishing technologies. Section 5.1.1 discusses the types and quantities of natural resources consumed during a surface finishing process operation, while section 5.1.2 focuses on other resources. Section 5.1.3 presents the conclusions drawn from this analysis.

5.1.1   Consumption of Natural Resources

Process resources that can be found naturally in the environment are considered to be natural resources. Over the last several years there has been a movement towards making society and the world more sustainable. By limiting the consumption of natural resources to a rate at which they can replenished, the availability of these precious resources will be assured for future generations. The concept of sustainability has been adopted by members of the manufacturing community as part of a successful environmental management program, meant to improve environmental performance and, by extension, profitability.

A surface finishing process primarily consumes two natural resources: water and metals. A comparative analysis of the rate of natural resource consumption by each of the surface finishing technologies is presented below.

Water Consumption

The surface finishing process line consists of a series of chemical baths which are typically separated by one or more water rinse steps. These water rinse steps account for virtually all of the water consumed during the operation of the surface finishing process. The water baths dissolve or displace residual chemicals from the panel surface, preventing contamination of subsequent baths, while creating a clean panel surface for future chemical activity. The number of rinse stages recommended by chemical suppliers for their surface finishing processes range from three to nine, but can actually be much higher depending on facility operating practices. The number of separate water rinse stages reported by respondents to the PWB Workplace Practices Questionnaire ranged from three to seventeen.

The flow rate required by each process rinse tank depends on several factors, including the time of panel submersion, the type and amount of chemical residue to be removed, the type of agitation used in the rinse stage, and the purity of rinse water. Because proper water rinsing is critical to the application of the surface finish, manufacturers often use more water than is required to ensure that panels are cleaned sufficiently. Other methods, such as flow control valves and sensors, are available to ensure that sufficient water is available to rinse PWB panels, while minimizing the amount of water consumed by the process.

PWB manufacturers often use multiple rinse water stages between chemical process steps to facilitate better rinsing. The first rinse stage removes the majority of residual chemicals and contaminants, while subsequent rinse stages remove any remaining chemicals. Counter-current or cascade rinse systems minimize water use by feeding the water effluent from the cleanest rinse tank, usually at the end of the cascade, into the next cleanest rinse stage, and so on, until the effluent from the most contaminated, initial rinse stage is sent for treatment or recycle. Other water reuse or recycle techniques include ion exchange, reverse osmosis, as well as reusing rinse water in other plant processes. A detailed description of methods to reduce water consumption, including methods to reuse or recycle contaminated rinse water, is presented in Chapter 6 of this CTSA.

Water consumption rates for each alternative were calculated using data collected from both the PWB Workplace Practices Questionnaire and from the Observer Data Sheets completed during the performance demonstration. Because of the wide variation in the overall, yearly production of the respondents, it was necessary to normalize the water consumption data to account for the variety in the overall throughput of the surface finishing process and the associated water consumption. The daily water consumption for each water rinse reported by a facility was divided by the overall daily production of the facility to develop a water consumption rate in gallons per ssf of PWB produced (gal/ssf) for each rinse. An average water consumption rate was then determined for each automation type and for any specialized rinse conditions (e.g., high pressure rinses). The resulting normalized flow rates for each water rinse type are shown in Table 5-2.

Table 5-2. Normalized Water Flow Rates of Various Water Rinse Types

Rinse Type	Normalized Water Flow Rate [a] (gal/ssf)
Water Rinse, Non-conveyorized	0.258
Water Rinse, Conveyorized	0.176
High Pressure Water Rinse, All automation types	0.465

[a] Data were normalized to account for differences in facility production rates by dividing the yearly water consumption by the total PWB produced for each facility. The individual normalized data points were then averaged.

The normalized flow rates were then combined with the standard configuration for each surface finishing technology (see Section 3.1, Source Release Assessment) to develop an overall water consumption rate for the entire surface finishing process line. The total water consumption rate for each surface finishing process was calculated by multiplying the number of rinse stages (Table 5-3) by the appropriate water flow rate (Table 5-2) for each water rinse category, then summing the results. The calculations are described by the following equation:

$$WCR_{total} = \sum [NRS_i \times NWCR_i]$$

where,

WCR_{total}	=	total water consumption rate (gal/ssf)
NRS_i	=	number of rinse water stages of type I
$NWCR_i$	=	normalized water consumption rate for rinse type I (gal/ssf)

The resulting overall rate represents the total water consumption for the entire surface finishing technology in gallons per ssf of PWB produced. Finally, the total volume of water consumed while producing 260,000 ssf was calculated using the total water consumption rate for the process. The number of rinse stages in a standard configuration of each technology, the water consumption rate of the entire surface finishing process, and the total water consumed by the application of the surface finish to 260,000 ssf of PWB for each technology is shown in Table 5-3. The amount of rinse water consumed for each alternative is also displayed graphically in Figure 5-1, from the lowest to the highest total consumption.

An analysis of the data shows that the type of surface finishing technology, as well as the level of automation, have a profound affect on the amount of water that a facility will consume during normal operation of the surface finishing process line. Five surface finishing processes consume less water than the baseline HASL process, including the conveyorized versions of the HASL, immersion silver, and immersion tin technologies, along with both versions of the organic solderability preservative (OSP) process. Three surface finishing processes consume more water than the baseline HASL process: the non-conveyorized versions of the immersion tin, nickel/gold, and the nickel/palladium/gold technologies.

**Table 5-3. Rinse Water Consumption Rates and Total Water
Consumed by Surface Finishing Technologies**

Surface Finishing Technology	No. of Rinse Stages [a]		Total Water Consumption Rate [b] (gal/ssf)	Rinse Water Consumed (gal/260,000 ssf)
	Normal Flow	High Pressure		
HASL, Non-conveyorized	3	1	1.24	3.22×10^5
HASL, Conveyorized	3	1	0.99	2.58×10^5
Nickel/Gold, Non-conveyorized	8	-	2.06	5.37×10^5
Nickel/Palladium/Gold, Non-conveyorized	14	-	3.61	9.39×10^5
OSP, Non-conveyorized	3	-	0.77	2.01×10^5
OSP, Conveyorized	3	-	0.53	1.37×10^5
Immersion Silver, conveyorized	3	-	0.53	1.37×10^5
Immersion Tin, Non-conveyorized	7	-	1.81	4.69×10^5
Immersion Tin, Conveyorized	5	-	0.88	2.29×10^5

[a] Data reflects the number of rinse stages required for the standard configuration of each surface finishing technology
as reported in Section 3.1, Source Release Assessment.
[b] Rinse water consumption rate was calculated by multiplying the number of rinse stages for each rinse type by the
corresponding consumption factor listed in Table 5-2. The individual rates were then totaled and divided by 1,000 to
determine the overall consumption rate for that technology.
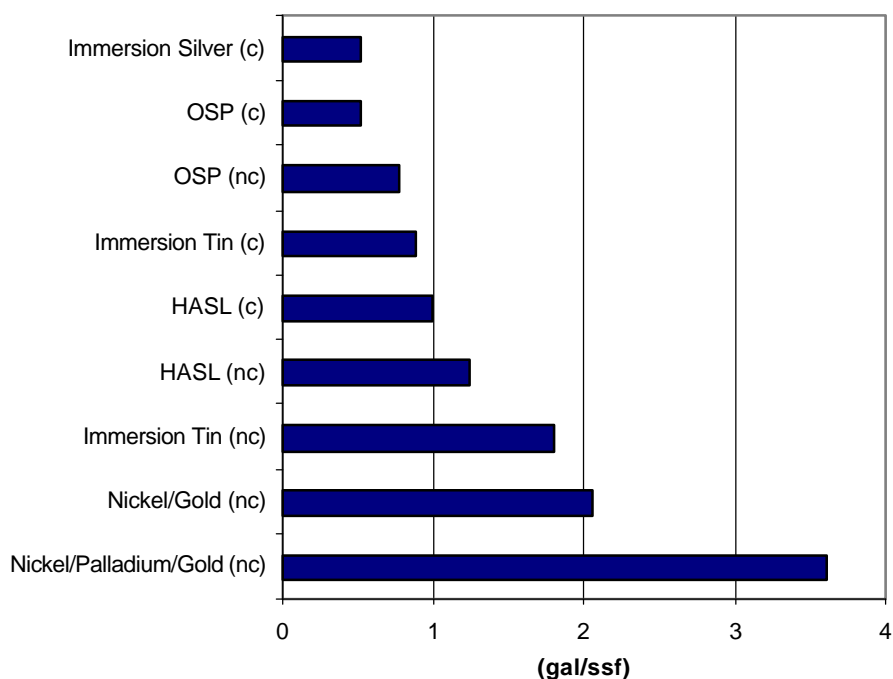
c: conveyorized
nc: non-conveyorized

Figure 5-1. Water Consumption Rates of Surface Finishing Technologies

The rate of water usage is primarily attributable to the number of rinse stages required by the processes. All of the processes with fewer rinse stages than the baseline HASL process show reduced water consumption, while all the processes that consumed more water had significantly more water rinse stages. Only the conveyorized immersion tin process had more water rinse steps than HASL while consuming less water, due primarily to the high pressure rinse tanks used by the HASL process.

The table also demonstrates that the conveyorized version of a process will consume less water during operation than the non-conveyorized version of the same process, a result attributed to the increased efficiency of the conveyorized processes over their non-conveyorized counterparts. The increased efficiency is a result of the higher throughput and shorter cycle time of the conveyorized systems, and is reflected in the normalized water flow rates for rinse stages for each automation type (Table 5-2).

To minimize water usage, some companies have gone a step farther by developing equipment systems that monitor water quality and usage in order to optimize water rinse performance. This pollution prevention technique is recommended to reduce both water consumption and wastewater generation. The actual water usage experienced by manufacturers employing such a system may be less than that calculated in Table 5-3.

Metal Consumption

Many of the surface finishes are formed by the deposition of metal ions onto the surface of the PWB, forming a reliable, solderable finish for further assembly. The metals range from relatively inexpensive, widely available metals such as tin and lead, found in solder, to expensive 'precious' metals such as silver, gold, and palladium. While a portion of the metal consumed can be found in the surface finish of the PWB, metal is also lost through drag-out of the plating bath to subsequent stages, and through the replacement of spent or contaminated plating solutions. In the case of HASL, solder is also lost through the continual removal of dross, a film of contaminated solder.

The amount of metal consumed through the deposition, or plating, of the surface finish is dependent on the thickness of the metal deposit, the amount of PWB surface area that must be plated, and the density of the metal being applied. The recommended plating thickness for a surface finishing technology can be obtained from the appropriate chemical supplier. In addition, plating specifications for surface finishes have been established through testing by both chemical suppliers and by industry. These specifications set forth strict guidelines on minimum plating thicknesses required to insure a reliable, solderable surface finish. The metal deposition rates and the total metal deposited by the surface finishing technologies are presented in Table 5-4.

Table 5-4. Metal Deposition Rates and Total Metal Consumed by Surface Finishing Technologies

Process	Metal	Density [a] (g/cm3)	Thickness [b] (µ in)	Metal Plated [c] (oz. per ssf)	Total Metal Consumed (lb/260K ssf)
HASL	Tin	7.4	126 [d]	0.0194	315
	Lead	11.4	74 [d]	0.0175	285
Nickel/Gold, Nickel/Palladium/Gold	Nickel	8.1	200	0.0337	547
	Palladium	12.0	6	0.0015	24.3
	Gold	19.3	7	0.0028	45.6
Immersion Silver	Silver	10.5	6	0.0013	21.3
Immersion Tin	Tin	7.4	25	0.0038	62.5

[a] Source: *Chemical Engineers' Handbook*, 1994.
[b] Thicknesses of deposits recommended by suppliers of individual product lines unless otherwise noted.
[c] Calculations assume that 25 percent of the PWB surface area requires metal deposition.
[d] Plating thickness calculated using a 200 µ in deposit and 63/37 tin-lead solder.

In addition to the metal consumed by the process through deposition or plating, metal is also lost through drag-out of bath chemicals into subsequent process baths and chemical degradation through contamination. Metal lost through drag-out along with other process chemicals were estimated with the use of a model developed specifically for estimating drag-out in the PWB surface finishing process. A description of the model along with model results are presented in Section 3.2.3 of the Exposure Assessment.

Calculating the metal lost to bath degradation and subsequent bath replacement is problematic due to the variability of metal ion concentrations at the time of replacement. The metal ion concentrations of plating baths are typically replenished regularly rather than replaced to maintain optimal operating conditions and to prevent depletion of the bath. However, because the metal baths are valuable, especially the ones containing precious metals, these baths are typically monitored very closely to prevent a build-up of contaminants and to minimize bath replacement. When replaced, the spent bath solutions are typically sent off for metal reclamation. Section 6.2.1, Recycle and Resource Recovery Opportunities, describes reclamation options and costs for various metals.

A significant amount of solder is also lost through the removal of dross during the operation of the HASL process. Dross is a solid film of contaminated solder that covers the top of the molten solder, requiring constant removal through either manual or mechanical means. Dross is composed of both copper contamination of the solder and the oxidation products of the tin-lead through contact with air. The amount of solder lost through dross removal can be significant, estimated to be as much as 90 percent of the solder consumed (Sharp, 2000), though much can be reclaimed through recycling. If not recycled, dross must be treated as a hazardous waste. A detailed discussion of solder recycling, including methods of recycling and reclamation costs, is presented in Section 6.2.1, Recycle and Resource Recovery Opportunities.

Table 5-4 shows that the use of HASL results in 600 pounds of metal being consumed through deposition onto the PWB, including 285 pounds of lead, a known environmental toxin. Only the nickel/palladium/gold process consumes nearly as much metal. It should be noted also that the values in Table 5-4 only reflect the metal deposited onto the PWBs and do not include any metal consumed or lost through drag-out, bath contamination, or any other losses such as dross removal. These losses can be significant as in the case of HASL, where the amount of lead consumed can be as much as 2,500 pounds if waste solder is not routinely recycled or reclaimed.

Although Table 5-4 shows the relative quantities of metal deposited, any determination of the relative importance of metal savings on the environment also must consider the availability of the metal, the toxicity of the metal at disposal, the price of the metal consumed, and the environmental impacts of mining the metal. While much of this impact analysis is beyond the scope of this project, the risks to human health and the environment are presented and discussed in Chapter 3, Risk Screening and Comparison. The cost of process chemicals containing the metals for each technology are presented in Section 4.2, Cost Analysis.

5.1.2   Consumption of Other Resources

Several resources consumed by the surface finishing processes fall under the category of man-made, rather than natural, resources. These include process chemicals, treatment chemicals, bath filters, board laminate, packaging waste, cleaning materials, and any other consumable materials. Both process chemicals and treatment chemicals are the only resources listed whose consumption rates are expected to vary significantly between the different surface finishing technologies. The remaining resources listed are of little concern to this comparative evaluation because they are either consumed in small quantities, or their consumption rate is not dependent on the type of surface finishing technology, and so will not vary greatly. A comparative analysis of the rate of consumption of man-made resources for each of the surface finishing technologies is presented below.

Process Chemicals Consumption

Bath chemicals that constitute the various chemical baths or process steps are consumed in large quantities during the normal operation of the surface finishing process, either through co-deposition with the metals onto the surface of the PWB or degradation through chemical reaction. Process chemicals are also lost through volatilization, bath depletion, bath drag-out to subsequent process stages, or contamination as PWBs are cycled through the surface finishing process. Lost or consumed process chemicals are replaced through chemical additions, or if the build-up of contaminants is too great, the bath is replaced. Methods for limiting unnecessary chemical loss and thus minimizing the amount of chemicals consumed are presented in Chapter 6 in this CTSA.

Presenting a chemical-by-chemical analysis of process chemical consumption is not possible without disclosing the composition and concentration of the proprietary chemical formulations collected from the chemical suppliers (the actual chemical consumption is a combination of the quantity and concentration of chemicals present, factors which vary greatly,

even with processes within a similar technology category). Legal constraints prevent the disclosure of this information. However, two of the primary conclusions drawn from the analysis are the effects of the chemical consumption on the process cost and on human health. These conclusions are presented in detail in the Risk Characterization (Section 3.4) and in the Cost Analysis (Section 4.2) portions of this document. A qualitative discussion of the factors found to contribute to the consumption of process chemicals is presented below.

Performing a comparative analysis of the process chemical consumption rates is problematic due to both the site-specific nature of many of the factors that contribute to process chemical consumption, and the differences in concentration and chemical composition of the solutions involved (i.e., would the consumption of one pound of hydrochloric acid be equivalent to one pound of ethylene glycol?). Factors affecting the rate at which process chemicals are consumed through the operation of the surface finishing process include:

- characteristics of the process chemicals (i.e., composition, concentration, volatility, etc.);
- process operating parameters (i.e., number of chemical baths, process throughput, automation, etc.); and
- bath maintenance procedures (i.e., frequency of bath replacement, replacement criteria, frequency of chemical additions, etc.).

The chemical characteristics of the process chemicals determine the rate at which chemicals are consumed in the surface finishing process. A chemical bath containing a highly volatile chemical, or mixture of chemicals, can experience significant chemical losses to the air. A more concentrated process bath will lose a greater amount of process chemicals in the same volume of drag-out than a less concentrated bath. These chemical characteristics not only vary among surface finishing alternatives, but can also vary considerably among surface finishing processes offered by different chemical suppliers within the same technology category.

The physical operating parameters of the surface finishing process also have a significant impact on the consumption rate of process chemicals. One such parameter is the number of chemical baths contained within the surface finishing process (the surface finishing process is comprised of several process stages, some of which are chemical process baths). The number of chemical process baths through which a panel must be processed to perform the surface finishing function varies widely among the technologies, with a corresponding affect on chemical consumption. The number of chemical baths (excluding rinse stages) range from three for OSP to eight in the nickel/palladium/gold technology. The process throughput, or quantity of PWBs passed through the surface finishing process, also affects chemical usage since the higher the throughput, the more process chemicals are consumed. However, conveyorized processes tend to consume less chemicals per ssf than non-conveyorized versions of the same process due to the smaller bath sizes and higher efficiencies of the automated processes.

The greatest impact on process chemical consumption can result from the bath maintenance procedures of the facility operating the process. The frequency with which baths are replaced and the bath replacement criteria used are key chemical consumption factors. Chemical suppliers typically recommend that chemical baths be replaced using established

testing criteria, such as concentration thresholds of bath constituents (e.g., 2 g/L of copper). Other bath replacement criteria include ssf of PWB processed and elapsed time since the last bath replacement. The practice of making regular adjustments to the bath chemistry through additions of process chemicals consumes process chemicals, but will extend the operating life of the process baths, reducing chemical use over time. Despite the supplier recommendations, project data showed a wide range of bath replacement practices and criteria for manufacturing facilities operating the same, as well as different, surface finishing technologies.

Wastewater Treatment Chemicals Consumption

The extent to which the consumption of treatment chemicals will be reduced, if any, is dependent on several factors, some of which include the rate at which wastewater is generated (e.g., the amount of rinse water consumed), the type of treatment chemicals used, composition of waste streams from other plant processes, percentage of treatment plant throughput attributable to the surface finishing process, the resulting reduction in surface finishing waste volume realized, and the extent to which the former surface finishing process was optimized for waste reduction. Because many of the above factors are site-specific and not dependent on the type of surface finishing process, a quantitative evaluation would not be meaningful. However, there is a direct correlation between the amount of treatment chemicals required and the amount of process chemicals lost to drag-out that must be treated. A description of a typical wastewater treatment process, along with the types of treatment chemicals used to treat contaminated wastewater, is presented in Section 6.2.2, Control Technologies.

Alternative treatment processes to conventional precipitation treatment may be available to reduce the amount of treatment chemical consumption depending on the type of surface finishing process being operated. A discussion of treatment options for each technology, including a treatment profile for each type of process bath, also is presented in Section 6.2.2, Control Technologies.

5.1.3 Summary and Conclusions

A comparative analysis of the water consumption rates was performed for the surface finishing technologies. A daily water flow rate was developed for each surface finishing technology using survey data provided by industry. Calculated water consumption rates ranged from a low of 0.53 gal/ssf for the immersion silver and OSP conveyorized processes, to a high of 3.6 gal/ssf for the non-conveyorized nickel/palladium/gold process. Several processes were found to consume less water than the HASL baseline including conveyorized versions of the immersion silver and immersion tin technologies, along with both versions of the OSP process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process. Primary factors influencing the water consumption rate included the number of rinse tanks and the overall efficiency of the conveyorized processes.

Metals are another natural resource consumed by a surface finishing process. The rate of deposition of metal was calculated for each technology along with the total amount of metal consumed for 260,000 ssf of PWB produced. It was shown that the consumption of close to 300

pounds of lead could be eliminated by replacing the baseline HASL process with an alternative technology. In cases where waste solder is not routinely recycled or reclaimed, the consumption of as much as 2,500 pounds of lead could be eliminated by replacement of the HASL process. Although several of the alternative technologies rely on the use of small quantities of other metals, the OSP technology eliminates metal consumption entirely. Other factors influencing metal consumption were identified and discussed.

A quantitative analysis of both process chemicals and treatment chemicals consumption could not be performed due to the variability of factors that affect the consumption of these resources, and for reasons of confidentiality. The role the surface finishing process has in the consumption of these resources was presented and the factors affecting the consumption rates were identified and discussed.

5.2 ENERGY IMPACTS

Energy conservation is an important goal for PWB manufacturers, as companies strive to cut costs and seek to improve environmental performance and global competitiveness. Energy use has become an important consideration in the manufacture of PWBs, as much of the manufacturing process requires potentially energy-intensive operations, such as heating the process baths. This is especially true during the operation of the surface finishing process, where energy is consumed by process equipment such as immersion heaters, fluid and air pumps, agitation devices such as vibrating motors, and by conveyorized transport systems. The focus of this section is to perform a comparative analysis of the relative energy consumption rates of the baseline HASL process and alternative surface finishing technologies.

Data collected for this analysis focus on the energy consumed during the application of the surface finish. Traditional life-cycle analysis indicates that energy consumption during other life-cycle stages also can be significant and should be considered when possible. Although a quantitative life-cycle analysis is beyond the scope and resources of this project, the impacts to the environment from the manufacture of the energy required by the surface finishing process is briefly analyzed and presented at the end of this chapter.

Section 5.2.1 discusses energy consumption during the application of the surface finish, while Section 5.2.2 discusses the environmental impacts of this energy consumption. Section 5.2.3 briefly discusses the energy consumption of other life-cycle stages. Section 5.2.4 presents conclusions of the comparative energy analysis.

5.2.1 Energy Consumption During Surface Finishing Process Operation

To determine the relative rates of energy consumption during the operation of the surface finishing technologies, specific data were collected regarding energy consumption through the Performance Demonstration project and through dissemination of the PWB Workplace Practices Questionnaire to industry members. Energy data collected include the following:

- process specifications (i.e., type of process, facility size, etc.);
- physical process parameters (i.e., number of process baths, bath size, bath conditions such as temperature and mixing, etc.);
- process automation (i.e., conveyorized, computer-controlled hoist, manual, etc.);
- equipment description (i.e., heater, pump, motor, etc.); and
- equipment energy specifications (i.e., electric load, duty, nominal power rating, horsepower, etc.).

Each of the surface finishing technologies contains a series of chemical baths that are typically separated by one or more water rinse steps. In some processes, these chemical stages are supplemented by other stages such as a drying oven or a HASL machine, which applies the solder to the PWB using a mechanical type of process. In order for the process to perform properly, each process stage should be operated within specific supplier recommended parameters, such as parameters for bath temperature and mixing, oven temperatures, or air knife

pressures. Maintaining these process stages within the desired parameters often requires energy-consuming equipment such as immersion heaters, fluid circulation pumps, and air compressors. In addition, the degree of process automation affects the relative rate of energy consumption. Clearly, conveyorized equipment requires energy to operate, but also non-conveyorized systems require additional equipment not found in conveyorized systems, such as panel agitation equipment.

Table 5-5 lists the types of energy-consuming equipment typically used during the operation of a surface finishing process and the function of the equipment. In some cases, one piece of equipment may be used to perform a function for the entire process line. For example, in a non-conveyorized system, panel vibration is typically performed by a single motor used to rock an apparatus that extends over all of the process tanks. The apparatus provides agitation to each individual panel rack that is connected to it, thus requiring only a single motor to provide agitation to every bath on the process line that may require it. Other equipment types such as immersion heaters affect only one process stage, so each process bath or stage may require a separate piece of energy-consuming equipment.

Table 5-5. Energy-Consuming Equipment Used in Surface Finishing Process Lines

Type of Equipment	Function
Conveyor Drive Motor	Powers the conveyor system required to transport PWB panels through the surface finishing process. Not required for non-conveyorized, vertical processes.
Immersion Heater	Raises and maintains temperature of a process bath to the optimal operating temperature.
Fluid Pump	Circulates bath fluid to promote flow of bath chemicals through drilled through holes and to assist filtering of impurities from bath chemistries.
Air Pump	Compresses and blows air into process baths to promote agitation of bath to ensure chemical penetration into drilled through holes. Also provides compressed air to processes using an air knife to remove residual chemicals from PWB panels.
Panel Agitation Motor	Moves the apparatus used to rock panel racks back and forth in process baths. Not required for conveyorized processes.
Gas Heater	Heats PWB panels to promote drying of residual moisture on the panel surface. Can also be used to cure a chemical coating.
Solder Pot	Melts solder and maintains the molten solder at optimal operating temperature, usually between 480 to 550 ^{o}F.
Ventilation Equipment	Provides ventilation required for surface finishing baths and to exhaust chemical fumes.

To assess the energy consumption rate for each surface finishing technology, an energy use profile was developed that identified typical sources of energy consumption during the application of the surface finish. The number of surface finishing process stages that result in the consumption of energy during operation was determined from Performance Demonstration and PWB Workplace Practices Questionnaire data. This information is listed in Table 5-6 according to the function of the energy-consuming equipment. For example, a typical non-conveyorized

OSP process consists of two heated chemical baths, three chemical baths requiring fluid circulation, two process stages requiring compressed air (for air knives in this case), and a single heated drying stage to cure the OSP coating. Panel agitation for the entire process is provided by a single motor used to rock an apparatus that extends over all of the process tanks. Ventilation equipment is not presented in Table 5-6 because the necessary data were not collected during the Performance Demonstration or in the PWB Workplace Practices Questionnaire. However, the amount of ventilation required varies according to the type of chemicals, bath operating conditions, and the configuration of the process line. Because they are enclosed, the ventilation equipment for conveyorized processes are typically more energy efficient than non-conveyorized processes.

Table 5-6. Number of Surface Finishing Process Stages that Consume Energy by Function of Equipment

Process Type	Function of Equipment [a]						
	Conveyor	Panel Agitation [b]	Bath Heat	Air Knife/ Sparging [c]	Fluid Circulation	Panel Drying	Solder Heater
HASL, Non-conveyorized	0	1	1	2	3	1	1
HASL, Conveyorized	1	0	1	2	4	1	1
Nickel/Gold, Non-conveyorized	0	1	4	1	3	0	0
Nickel/Palladium/Gold, Non-conveyorized	0	1	6	1	3	0	0
OSP, Non-conveyorized	0	1	2	2	3	1	0
OSP, Conveyorized	1	0	2	2	3	1	0
Immersion Silver, Conveyorized	1	0	2	0	4	1	0
Immersion Tin, Non-conveyorized	0	1	3	0	4	1	0
Immersion Tin, Conveyorized	1	0	3	0	3	1	0

[a] Table entries for each surface finishing alternative represent the number of process stages requiring each specific function. All functions are supplied by electric equipment, except for drying, which is performed by gas-fired oven.
[b] Processes reporting panel agitation for one or more process stages are entered as one in the summary regardless of the number since a single motor can provide agitation for the entire process line.
[c] Air sparging is used selectively by some manufacturers to enhance bath performance. Sparging may not be required for all product lines or facilities using a surface finishing technology.

The electrical energy consumption of surface finishing line equipment, as well as equipment specifications (power rating, average duty, and operating load), were collected during the Performance Demonstration. In cases where electricity consumption data were not available, the electricity consumption rate was calculated using the following equation:

$$EC = NPR \times OL \times AD \times (1kW/0.746 \text{ HP})$$

where,

EC	=	electricity consumption rate (kWh/day)
NPR	=	nominal power rating (HP)
OL	=	operating load (percent), or the percentage of the maximum load or output of the equipment that is being used
AD	=	average duty (hr/day), or the amount of time per day that the equipment is being operated at the operating load

Electricity consumption data for each equipment category were averaged to determine the average amount of electricity consumed per hour of operation for each type of equipment per process. The natural gas consumption rate for a drying oven was supplied by an equipment vendor. Electricity and natural gas consumption rates for surface finishing equipment per process stage are presented in Table 5-7.

Table 5-7. Energy Consumption Rates for Surface Finishing Equipment

Function of Equipment	Type of Equipment	Energy Consumption Rates Per Equipment Type	
		Electricity [a] (kW)	Natural Gas [b] (ft^3/hr)
Conveyorized Panel Automation	Conveyor System	14.1	-
Panel Agitation	Panel Agitation Motor	3.1	-
Bath Heater	Immersion Heater	4.1	-
Fluid Circulation	Fluid Pump	0.9	-
Air Knife/Sparging	Air Pump	3.8	-
Panel Drying	Gas Drying Oven	-	90
Solder Heater	Solder Pot	20	

[a] Electricity consumption rates for each type of equipment were calculated by averaging energy consumption data per stage from the performance demonstrations. If required, consumption data were calculated from device specifications and converted to total kW per bath using 1 HP = 0.746 kW.
[b] Natural gas consumption rate for the gas heater was estimated by an equipment vendor (Exair Corp.).

The total electricity consumption rate for each surface finishing alternative was calculated by multiplying the number of process stages that consume electricity (Table 5-6) by the appropriate electricity consumption rate (Table 5-7) for each equipment category, then summing the results. The calculations are described by the following equation:

$$ECR_{total} = \sum [NPS_i \; x \; ECR_i]$$

where,

ECR_{total}	=	total electricity consumption rate (kW)
NPS_i	=	number of process stages requiring equipment i
ECR_i	=	energy consumption rate for equipment i (kW)

Natural gas consumption rates were calculated using a similar method. The individual energy consumption rates for both natural gas and electricity were then converted to British Thermal Units (Btu) per hour and summed to give the total energy consumption rate for each surface finishing technology. The individual consumption rates for both natural gas and electricity, as well as the hourly energy consumption rate calculated for each of the surface finishing technologies, are listed in Table 5-8.

These energy consumption rates include only the types of equipment listed in Table 5-5, which are commonly recommended by chemical suppliers to successfully operate a surface finishing process. However, equipment such as ultrasonics, automated chemical feed pumps, vibration units, panel feed systems, or other types of electrically powered equipment may be part of the surface process line. The use of this equipment may improve the performance of the surface finishing process, but is not required in a typical process for any of the surface finishing technologies.

Table 5-8. Hourly Energy Consumption Rates for Surface Finishing Technologies

Process Type	Energy Consumption Rates		Hourly Consumption Rate [a] (Btu/hr)
	Electricity (kW)	Natural Gas (ft³/hr)	
HASL, Non-conveyorized	37.5	90	219,800
HASL, Conveyorized	49.4	90	260,400
Nickel/Gold, Non-conveyorized	26.0	-	88,700
Nickel/Palladium/Gold, Non-conveyorized	34.2	-	116,700
OSP, Non-conveyorized	21.6	90	165,500
OSP, Conveyorized	32.6	90	203,100
Immersion Silver, Conveyorized	25.9	90	180,200
Immersion Tin, Non-conveyorized	19.0	90	156,700
Immersion Tin, Conveyorized	29.1	90	191,100

[a] Electrical energy was converted at the rate of 3,413 Btu per kilowatt hour. Natural gas consumption was converted at the rate of 1,020 Btu per cubic feet of gas consumed.

To determine the overall amount of energy consumed by each technology, the hourly energy consumption rate from Table 5-8 was multiplied by the amount of time needed for each alternative to manufacture 260,000 ssf of PWB (the average HASL throughput of respondents to the PWB Workplace Practices Questionnaire). Because insufficient survey data exist to accurately estimate the amount of time required for each process to produce the 260,000 ssf of board, the operating time was simulated using a computer model developed for each surface finishing technology. The results of the simulation, along with a discussion of the data and parameters used to define each technology, are presented in Section 4.2, Cost Analysis. The hours of surface finishing operation required to produce 260,000 ssf of board from the simulation, the total amount of energy consumed, and the energy consumption rate per ssf of board produced for each technology are presented in Table 5-9.

**Table 5-9. Energy Consumption Rate per ssf of PWB Produced
for Surface Finishing Technologies**

Process Type	Process Operating Time [a] (hours)	Total Energy Consumed (Btu/260,000 ssf)	Energy Consumption Rate (Btu/ssf)
HASL, Non-conveyorized	258	5.67×10^7	218
HASL, Conveyorized	133	3.46×10^7	133
Nickel/Gold, Non-conveyorized	1,310	1.16×10^8	447
Nickel/Palladium/Gold, Non-conveyorized	1,710	2.00×10^8	768
OSP, Non-conveyorized	197	3.26×10^7	125
OSP, Conveyorized	93	1.89×10^7	73
Immersion Silver, Conveyorized	414	7.46×10^7	287
Immersion Tin, Non-conveyorized	480	7.52×10^7	289
Immersion Tin, Conveyorized	710	1.36×10^8	522

[a] Times listed represent the operating time required to manufacture 260,000 ssf of PWB by each process as simulated by computer model. Operating time was considered to be the overall process time minus the downtime of the process.

Table 5-9 shows that three of the process alternatives consumed less energy than the baseline, non-conveyorized, HASL process. Both the non-conveyorized and conveyorized versions of the OSP process, along with the conveyorized HASL process, consumed significantly less energy than the baseline process. The reductions were primarily attributable to the efficiency of the three processes, which resulted in operating times significantly less than that of the traditional non-conveyorized HASL process. Both the immersion silver process and the conveyorized immersion tin processes performed roughly equal to the baseline process, utilizing a lower hourly consumption rate to offset a small disadvantage in operating time.

Three processes consumed significantly more energy than the baseline process. Despite having the lowest hourly consumption rate of all the surface finishing technologies, the nickel/gold process consumed more than twice the energy of the baseline due to its long process operating time. Other processes with high energy consumption rates include nickel/palladium/gold and conveyorized immersion tin.

The performance of specific surface finishing technologies with respect to energy is primarily dependent on the hourly energy consumption rate (Table 5-8) and the overall operating time for the process (Table 5-9). Non-conveyorized processes typically have lower hourly consumption rates than conveyorized processes of the same type because the operation of conveyorized equipment is more energy-intensive. Although conveyorized processes typically have higher hourly consumption rates, these differences are usually more than offset by the shorter operating times that are required to produce an equivalent quantity of PWBs.

When the non-conveyorized and conveyorized versions of a surface finishing technology are compared, the conveyorized versions of the technology seem to be typically more energy efficient. Table 5-10 compares the energy consumption data for those technologies that are

operated in both conveyorized and non-conveyorized modes. This table shows that, although the conveyorized version of all three processes requires more energy *per hour* to operate than the non-conveyorized mode, the added efficiency of the conveyorized system (reflected in the shorter operating time) results in less energy usage per ssf of board produced. The immersion tin processes are the exceptions. The non-conveyorized configuration of this process not only has a better hourly consumption rate than the conveyorized, but also benefits from a faster operating time, a condition due to the long overall cycle-time required for the conveyorized process. These factors combine to give the non-conveyorized immersion tin process a lower energy consumption rate than the conveyorized version. Despite this exception, the overall efficiency of conveyorized systems typically will result in less energy usage per ssf of board produced, as it did for both the HASL and OSP processes.

**Table 5-10. Effects of Automation on Energy Consumption
for Surface Finishing Technologies**

Process Type	Hourly Consumption Rate (1,000 Btu/ssf)	Process Operating Time [a] (hours)	Energy Consumption Rate (Btu/ssf)
HASL, Non-conveyorized	220	258	218
HASL, Conveyorized	260	133	133
OSP, Non-conveyorized	165	197	125
OSP, Conveyorized	203	93	73
Immersion Tin, Non-conveyorized	156	480	289
Immersion Tin, Conveyorized	191	710	522

[a] Times listed represent the operating time required to manufacture 260,000 ssf of PWB by each process as simulated by computer model. Operating time was considered to be the overall process time minus the downtime of the process.

Finally, it should be noted that the overall energy use experienced by a facility will depend greatly upon the operating practices and the energy conservation measures adopted by that facility. To minimize energy use, several simple energy conservation opportunities are available and should be implemented. These include insulating heated process baths, using thermostats on heaters, and turning off equipment when not in use.

5.2.2   Energy Consumption Environmental Impacts

The production of energy results in the release of pollution into the environment, including pollutants such as carbon dioxide (CO_2), sulfur oxides (SO_x), carbon monoxide (CO), sulfuric acid (H_2SO_4), and particulate matter. The type and quantity of pollution depends on the method of energy production. Typical energy production facilities in the U.S. include hydroelectric, nuclear, and coal-fired generating plants.

The environmental impacts attributable to energy production resulting from the differences in energy consumption among surface finishing technologies were evaluated using a computer program developed by the EPA National Risk Management Research Laboratory, *P2P-*

version 1.50214 (U.S. EPA, 1994). This program can, among other things, estimate the type and quantity of pollutant releases resulting from the production of energy as long as the differences in energy consumption and the source of the energy used (e.g., electrical energy from a coal-fired generating plant, thermal energy from a oil-fired boiler, etc.) are known. The program uses data reflecting the "national average" pollution releases per kilowatt-hour derived from particular sources. Electrical power derived from the average national power grid was selected as the source of electrical energy, while natural gas was used as the source of thermal energy for this evaluation. Energy consumption rates from Table 5-8 were multiplied by the operating time required to produce 260,000 ssf of board reported for each technology in Table 5-9. These totals were then divided by 260,000 to get the electrical and thermal energy consumed per ssf of board, which were then used as the basis for the analysis. Results of the environmental impact analysis from energy production are summarized and presented in Table 5-11. Appendix H contains printouts from the P2P program for each alternative.

Although the pollutant releases reported in Table 5-11 are combined for all media (i.e., air, water, and land), they often occur in one or more media, where they may present different hazards to human health or the environment. To allow a comparison of the relative effects of any pollution that may occur, it is necessary to identify the media of releases. Table 5-12 displays the pollutants released during the production of energy, the media into which they are released, and the environmental and human health concerns associated with each pollutant.

The information presented in Tables 5-11 and 5-12 show that the generation of energy is not without environmental consequences. Pollutants released to air, water, and soil resulting from energy generation can pose direct threats to both human health and the environment. As such, the consumption of energy by the surface finishing process contributes directly to the type and magnitude of these pollutant releases. Primary pollutants released from the production of electricity include CO_2, solid wastes, SO_x, and nitrogen oxides. These pollutants contribute to a wide range of environmental and human health concerns. Natural gas consumption results primarily in releases of CO_2 and hydrocarbons, which typically contribute to environmental problems such as global warming and smog. Minimizing the amount of energy usage by the surface finishing process, either by selection of a more energy efficient process or by adopting energy efficient operating practices, will decrease the quantity of pollutants released into the environment resulting from the generation of the energy consumed.

Table 5-11. Pollution Resulting From the Generation of Energy Consumed by Surface Finishing Technologies

Surface Finishing Alternative	Types of Pollutants Released (g/ssf) [a]								
	Carbon Dioxide (CO₂)	Carbon Monoxide (CO)	Dissolved Solids	Hydrocarbons	Nitrogen Oxides (NOₓ)	Particulates	Solid Wastes	Sulfur Oxides (SOₓ)	Sulfuric Acid (H₂SO₄)
HASL, Non-conveyorized	20	0.026	0.004	0.051	0.079	0.029	2.1	0.16	0.013
HASL, Conveyorized	31	0.039	0.005	0.089	0.124	0.043	3.1	0.23	0.019
Nickel/Gold, Non-conveyorized	92	0.13	0.017	0.11	0.402	0.15	11	0.80	0.067
Nickel/Palladium/Gold, Non-conveyorized	160	0.22	0.030	0.19	0.681	0.26	19	1.4	0.12
OSP, Non-conveyorized	15	0.018	0.003	0.058	0.054	0.019	1.4	0.10	0.008
OSP, Conveyorized	10	0.013	0.002	0.031	0.039	0.014	1.0	0.075	0.006
Immersion Silver, Conveyorized	38	0.044	0.006	0.13	0.134	0.048	3.5	0.26	0.021
Immersion Tin, Non-conveyorized	35	0.039	0.006	0.14	0.124	0.041	3.0	0.22	0.018
Immersion Tin, Conveyorized	70	0.085	0.012	0.23	0.258	0.093	6.7	0.49	0.041

[a] Pollutant totals calculated using the computer program *P2P version 2.70707* developed by EPA's National Risk Management Research Laboratory.

Table 5-12. Pollutant Environmental and Human Health Concerns

Pollutant	Medium of Release	Environmental and Human Health Concerns
Carbon Dioxide (CO_2)	Air	Global warming
Carbon Monoxide (CO)	Air	Toxic organic,[a] smog
Dissolved Solids	Water	Dissolved solids [b]
Hydrocarbons	Air	Odorant, smog
Nitrogen Oxides (NO_x)	Air	Toxic inorganic,[a] acid rain, corrosive, global warming, smog
Particulates	Air	Particulates [c]
Solid Wastes	Soil	Land disposal capacity
Sulfur Oxides (SO_x)	Air	Toxic inorganic,[a] acid rain, corrosive
Sulfuric Acid (H_2SO_4)	Water	Corrosive, dissolved solids [b]

[a] Toxic organic and inorganic pollutants can result in adverse health effects in humans and wildlife.

[b] Dissolved solids are a measure of water purity and can negatively affect aquatic life as well as the future use of the water (e.g., salinity can affect the water's effectiveness at crop irrigation).

[c] Particulate releases can promote respiratory illness in humans.

5.2.3   Energy Consumption in Other Life-Cycle Stages

When performing a comparative evaluation among surface finishing technologies, the energy consumed throughout the entire life cycle of the chemical products in the technology should be considered. The product use phase is only one aspect of the environmental performance of a product. A life-cycle analysis considers all stages of the life of a product, beginning with the extraction of raw materials from the environment, and continuing on through the manufacture, transportation, use, recycle, and ultimate disposal of the product.

Each stage within this life cycle consumes energy. It is possible for a product to be energy efficient during the use phase of the life cycle, yet require large amounts of energy to manufacture or dispose of the product. There are energy consumption differences also in the transportation of wastes generated by a surface finishing process. The transportation of large quantities of sludge resulting from the treatment of processes with chelated waste streams (i.e., nickel/gold) will consume more energy than the transportation of smaller quantities of sludge resulting from processes that do not use chelators. These examples show that energy use from other life-cycle stages can be significant and should be considered when evaluating the energy performance of a product. However, a comprehensive assessment of other life-cycle stages was beyond the scope of this study.

5.2.4   Summary and Conclusions

A comparative analysis of the relative energy consumption rates was performed for the surface finishing technologies. An hourly energy consumption rate was developed for the baseline non-conveyorized HASL process and each alternative using data collected from industry through a survey. A computer simulation was used to determine the operating time required to produce 260,000 ssf of PWB, and an energy consumption rate per ssf of PWB was calculated. The energy consumption rates ranged from 73 Btu/ssf for the conveyorized OSP process to 768 Btu/ssf for the non-conveyorized nickel/palladium/gold process. The results indicate that three surface finishing processes are more energy efficient than the traditional non-conveyorized HASL process, while two others are roughly comparable. It was found also that for alternatives with
both types of automation, the conveyorized version of the process is typically the more energy efficient (HASL and OSP), with the notable exception of the immersion tin process.

An analysis of the impacts directly resulting from the production of energy consumed by the surface finishing process showed that generation of the required energy is not without environmental consequence. Pollutants released to air, water, and soil can result in damage to both human health and the environment. The consumption of natural gas tends to result in releases to the air which contribute to odor, smog and global warming, while the generation of electricity can result in pollutant releases to all media, with a wide range of possible affects. Minimizing the amount of energy usage by the surface finishing process, either by selection of a more energy efficient process or by adopting energy efficient operating practices, will decrease the quantity of pollutants released into the environment resulting from the generation of the energy consumed.

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